

NEW TECHNIQUE FOR CRYOGENICALLY COOLING SMALL TEST ARTICLES

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Summary – Convective heat removal techniques to rapidly cool small test articles to Earth-Moon L₂ temperatures of 77 K were accomplished through the use of liquid nitrogen (LN₂). By maintaining a selected pressure range on the saturation curve, test articles were cooled below the LN₂ boiling point at ambient pressure in less than 30 min. Difficulties in achieving test pressures while maintaining the temperature tolerance necessitated a modification to the original system to include a closed loop conductive cold plate and cryogenic shroud.

INTRODUCTION

The White Sands Test Facility (WSTF) Remote Hypervelocity Test Laboratory (RHTL) developed a system to rapidly remove heat from small test articles using liquid nitrogen (LN₂). The system is capable of achieving a variety of cold temperatures to mimic the near earth orbit or deep space environments where temperatures are near 77 K (-321 °F). Temperatures for individual test series vary, so the WSTF team developed a system capable of rapid response while obtaining the temperatures required by WSTF customers.

FACILITY AND LAUNCHER



Fig. 1
0.17-Caliber Launcher

The RHTL utilizes a 0.17-caliber two-stage launcher (Fig. 1) to accelerate single 0.05 mm - 3.6 mm projectiles to 8.2 km/s. Velocity is captured using laser intervalometers and flash detectors. The primary data acquisition system is used to record events such as trigger, laser breaks, and impact flashes from the launcher. An independent 100 MHz data acquisition system (Fig. 2) is used to collect temperature data on the front and back surfaces of the test

articles. This system has a large storage capacity capable of recording data at various sampling rates throughout the test process.



Fig. 2
Temperature Data Acquisition Computer

COOLING SYSTEM CONFIGURATION

Lessons learned from past use of LN₂ and cold plate systems demonstrated that it is difficult and time consuming to achieve 77 K (-321 °F) to replicate the predicted Earth-Moon L₂ temperatures. After referring to a previously developed WSTF LN₂ injection system, the design team recommended an LN₂ spray system housed within a stainless steel cubicle enclosure with only one 19 mm (¾-in.) opening to allow the projectile through. The RHTL-developed system would require a careful balance between LN₂ feed and vacuum to avoid the triple point on the LN₂ saturation curve [1].

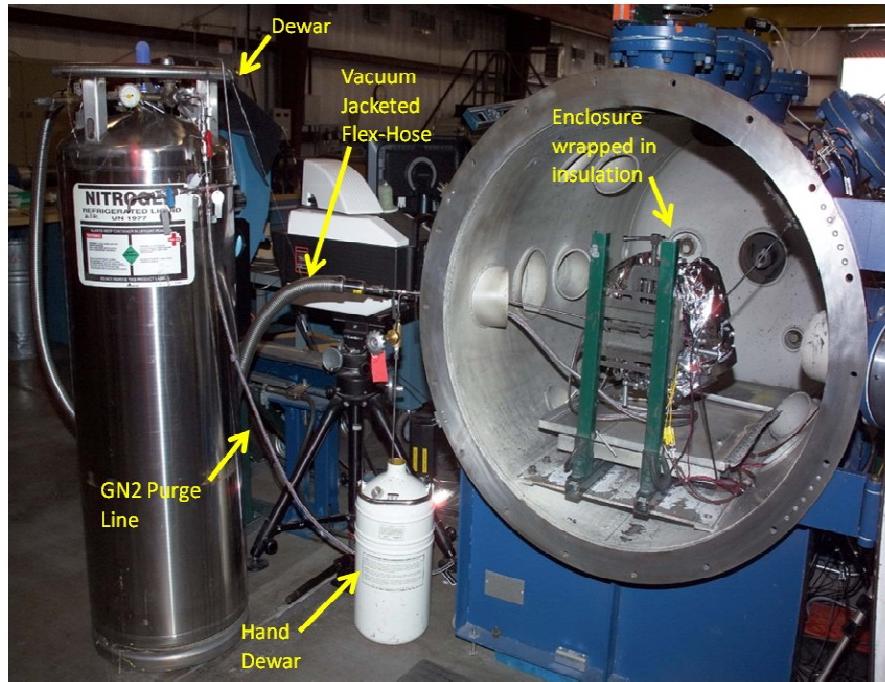


Fig. 3

Liquid Nitrogen Delivery System and Enclosure

The LN₂ delivery system (Fig. 3) consisted of a LN₂ Dewar with gaseous nitrogen (GN₂) supplied for head pressure and purge gas. To protect the Dewar and avoid liquid lock on the delivery system, a cryogenic safety relief valve was installed. A cryogenic supply feed-through was installed in a port of the target tank and a standard AN feed-through was installed on the same plate exiting the target tank. The LN₂ flowed through the system and then fed into a hand Dewar allowing the excess to boil off to atmosphere. To minimize loss, a vacuum-jacketed refrigerant line was used to transport LN₂ from the Dewar to the target tank. Inside the target tank, standard flex hoses mated the cryogenic feed-through to the AN fitting on the enclosure. The spray nozzle consisted of a two-holed orifice drilled 45-degrees apart into a 6.35 mm (1/4-in.) flared tubing orifice cap.

Based on Wells' cryogenic system [2], insulation and black body reflective material were used to insulate the sample from the chamber walls and reduce blackbody radiation. The WSTF design team used extreme temperature insulation (Fig. 4), which was installed on all surfaces and between the mounting fixtures to help minimize conduction from the target support fixture. Metalized polyethylene terephthalate (MPET), also known as foil survival blankets, was used to wrap the entire enclosure (Fig. 5) to further limit heat gain and minimize blackbody radiation from the target tank and support equipment.



Fig. 4
Insulation & MPET

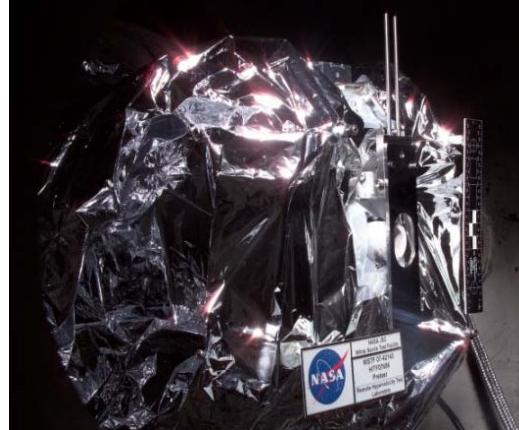


Fig. 5
MPET Overwrap

A Busch Semiconductor Cobra DL80 vacuum pump with a capacity of approximately 1.4 actual cubic meters per minute (51 ft³/min) at ambient pressure was used to maintain target tank pressures near 150 Torr. This technique was used to achieve lower temperatures of the GN₂ as seen in Fig. 6, but also required diligence to open and close the vacuum valve.

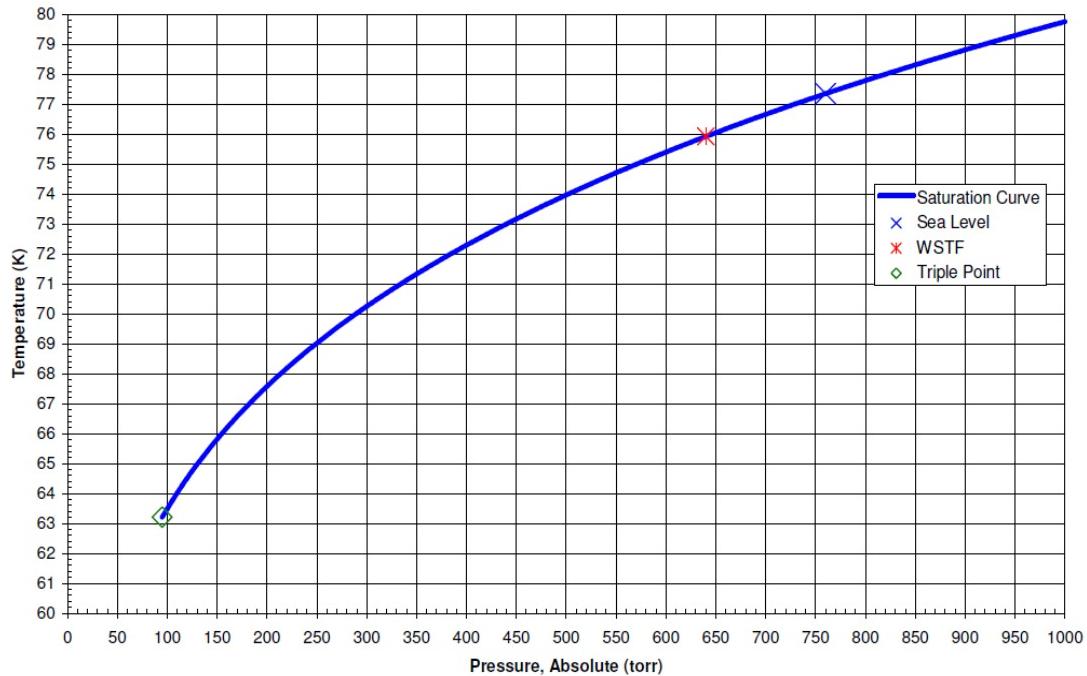


Fig. 6
Liquid Nitrogen Saturation Curve

RESULTS

RHTL has performed two test series requiring temperatures below 89 K (-300 °F). The first was in support of the James Webb Space Telescope (JWST) in 2007 and utilized the system described above. The second was in support of the In-Space Propulsion Program for Aerocapture missions in 2011.

James Webb Space Telescope Series (JWST)

Overall, the JWST tests were completed adequately. Test temperatures were typically obtained within 30 min (Fig. 7) and the test articles experienced uniform cooling (Fig. 8) at the front, back, and internal thermocouple locations.

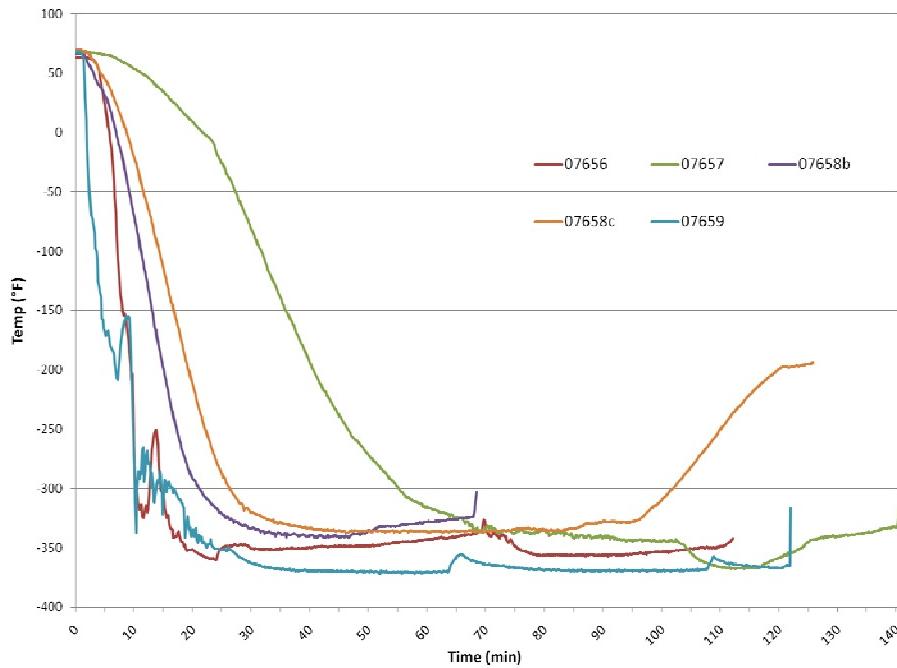


Fig. 7
JWST Cooling Data

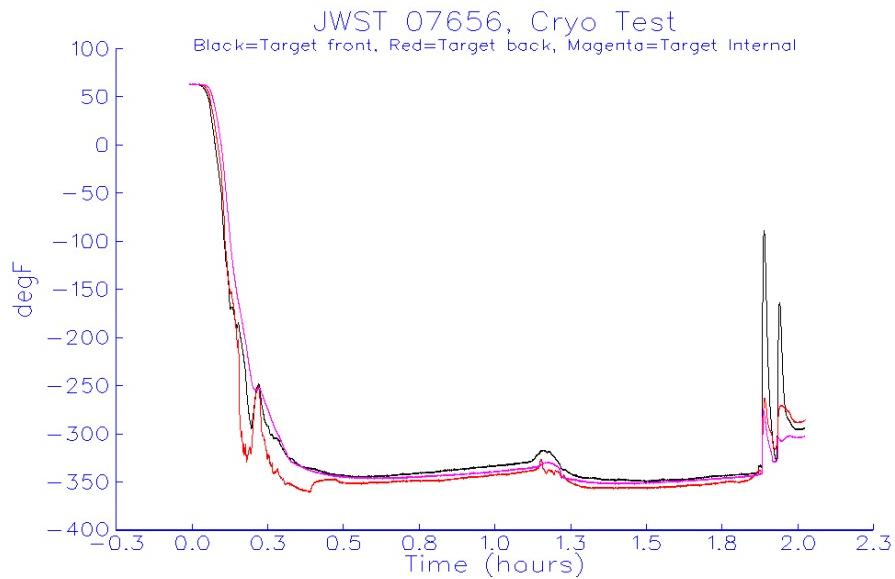


Fig. 8
Uniform Cooling of Test Article

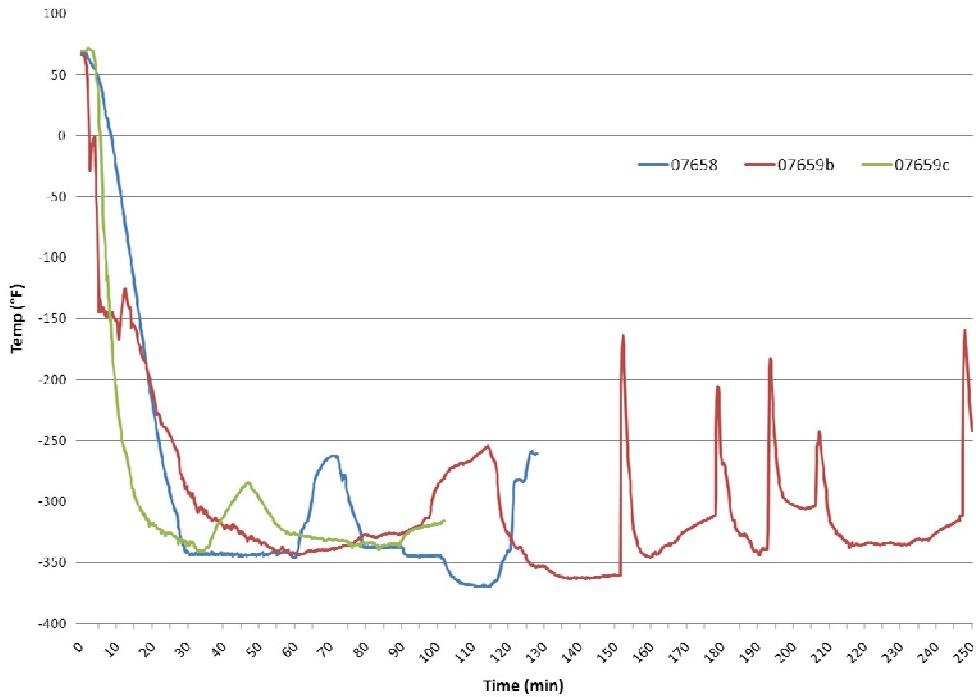


Fig. 9
Temperature Fluctuations due to Icing

There was difficulty in keeping the test article within the test temperatures while the vacuum pump pulled to the required test vacuum below 2.5 Torr. A major difficulty encountered was that when the system cooled down, LN₂ was drawn into the enclosure and sometimes into the target tank. The additional vaporization from the LN₂ inside the target tank prevented the vacuum pump from pulling to test pressures because of the formation of nitrogen ice once the pressure got down to the triple point. To warm the ice, GN₂ was reintroduced into the system to bring the pressure and temperature back up (Fig. 9). Lack of visibility into the stainless steel enclosure prevented direct observation of the LN₂ or nitrogen ice so it was never certain when it had completely vaporized. Once it was suspected that the vaporization was complete at the higher pressures and temperatures, the spray-down system was reinitiated to remove the heat gained back into the article. Several iterations of this process were usually required and a few times tests were scrubbed. The spray system was difficult to balance.

Aerocapture Series

The second test series required a temperature range of approximately $83 \text{ K} \pm 6 \text{ K}$ ($-310 \pm 10^\circ\text{F}$). A cryogenic shroud provided by Marshall Space Flight Center (MSFC) was utilized at first as the sole cooling system for the test articles as part of the test requirements. The shroud surrounded the test article (Fig. 10) but the cooling method was conduction only through the back plate of the shroud. Initial attempts using the shroud yielded temperatures of 144 K (-200°F) within 30 min, but after 100 min the test article never got below 128 K (-230°F).

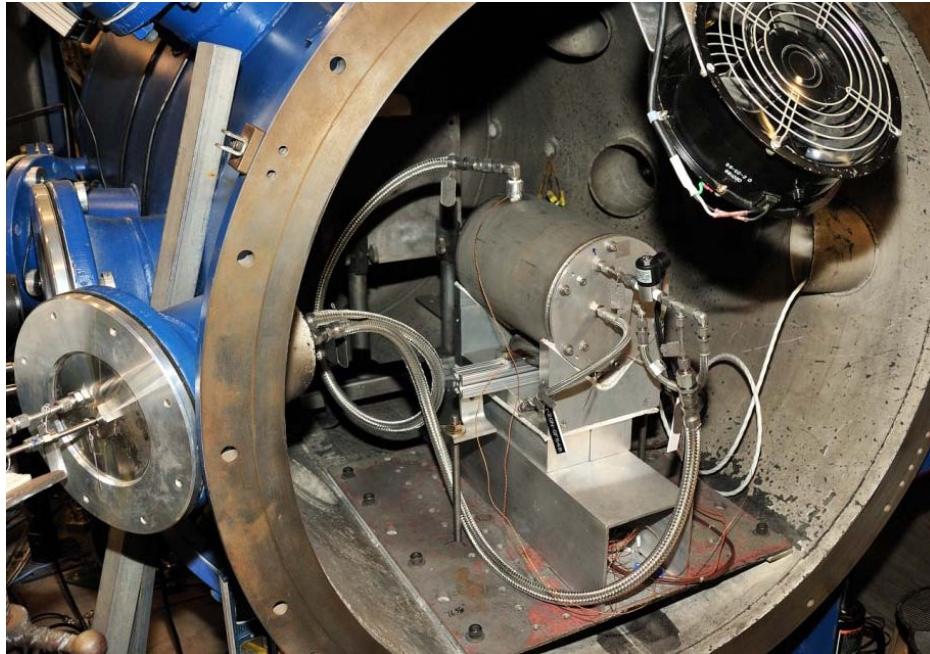


Fig. 10
Cryogenic Shroud

To satisfy the required test parameters and schedule, a cryogen coil and a modified LN₂ spray system based on the JWST configuration was added to the shroud system. The coil consisted of copper tubing bent into a spiral shape and clamped to the back of the test article mounting plate (Fig. 11). The target was installed with a 12.7 cm (5-in.) gap from the back of the shroud, and the cryogenic coil system was placed in direct contact with the back of the test article. The hypothesis was that the cryogenic coil line would provide conduction with LN₂ on the back of the test article while the spray system and reduced vacuum technique cooled the article through convection. When the test temperature was reached, the spray system was deactivated and the cold loop maintained the temperature while the proper test vacuum was achieved (Fig. 12).



Fig. 11
Cryogenic Coil

When operating procedures were tuned, 77 K (-321 °F) was achieved within 30 min; test pressures of less than 2.5 Torr and testing occurred within 35 min of initiating the LN₂ systems. Ironically, the process required much less time to remove heat than it did to put it back in during posttest reheating. The target tank could not be opened until the temperature was above the dew point to eliminate the chance of frost buildup on the target. Initially the posttest heating required ~2 ½ hours, so a heat plate was installed below the shroud and ambient temperature GN₂ was forced through the tubing system to reduce the reheating process to about 1 hour.

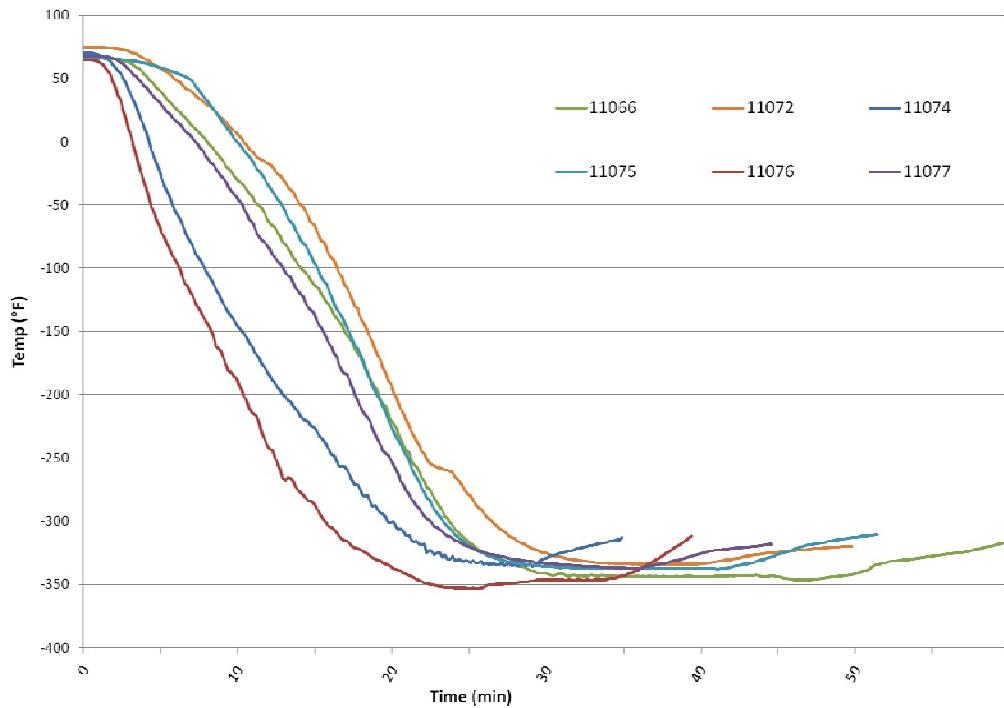


Fig. 12
Convective and Conductive Cooling

SUMMARY AND CONCLUSION

The team successfully developed and implemented a combined convective and conductive cooling system which permitted rapid cooling to 77 K (-321 °F) without adversely affecting the ability to reach test pressures. With the LN₂ spray system and the combined spray, coil, and shroud systems, the problem of injecting LN₂ occurred. However, it was easier to avoid with the combined system. Future work will investigate methods of eliminating the conditions that cause the injection of LN₂ into the target tank with an orifice or regulator installed prior to the cryogenic valve. The orifice might increase the time required to remove the heat but would reduce the flow sufficiently to mitigate LN₂ injection. The regulator would allow adjustment to reduce flow as the temperature falls, decreasing the amount of time required. Another area for investigation will explore cooling multi-layered test articles and articles of more substantive mass.

The convective-only system presented difficulties in obtaining and maintaining test parameters as the test article temperature rose rapidly and the conduction-only system was unable to obtain temperatures below 130 K (-225 °F). However, the combined system consisting of the cryogenic shroud, coil, and LN₂ spray system provided the necessary stable heat removal capability to meet test objectives.

ACKNOWLEDGEMENTS

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- [1] Anderson, J. *WSTF Sketch and Calculation Database, Saturation Curve for Liquid Nitrogen*. Sketch #JCA 2635. NASA White Sands Test Facility, Las Cruces, NM, 2007.
- [2] Wells, B.K. "Cryogenic and Elevated Temperature Hypervelocity Impact Facility." *International Journal of Impact Engineering*. Hypervelocity Impact Proceedings of 2005 Symposium. Vol. 33 (2006): pp 855-861.